John E. McMurry • Robert C. Fay

General Chemistry: Atoms First

Chapter 1
Chemistry: Matter and Measurement

Lecture Notes

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Chemistry and the Elements

TABLE 1.1 Names and Symbols of Some Common Elements

Aluminum	**Al**	Chlorine	**Cl**	Manganese	**Mn**	Copper (*cuprum*)	**Cu**
Argon	**Ar**	Fluorine	**F**	Nitrogen	**N**	Iron (*ferrum*)	**Fe**
Barium	**Ba**	Helium	**He**	Oxygen	**O**	Lead (*plumbum*)	**Pb**
Boron	**B**	Hydrogen	**H**	Phosphorus	**P**	Mercury (*hydrargyrum*)	**Hg**
Bromine	**Br**	Iodine	**I**	Silicon	**Si**	Potassium (*kalium*)	**K**
Calcium	**Ca**	Lithium	**Li**	Sulfur	**S**	Silver (*argentum*)	**Ag**
Carbon	**C**	Magnesium	**Mg**	Zinc	**Zn**	Sodium (*natrium*)	**Na**

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The Periodic Table

- Professor Dmitri Mendeleev published the first Periodic Table of the Atomic Elements in 1869 based on properties which appeared with some regularity as he laid out the elements from lightest to heaviest. [1]
- When Mendeleev proposed his periodic table, he noted gaps in the table, and predicted that unknown elements existed with appropriate properties to fill those gaps.

Elements and the Periodic Table

Mendeleev's Periodic Table (1871)

H = 1						
Li = 7	Be = 9.4		B = 11	C = 12	N = 14	O = 16	F = 19
Na = 23	Mg = 24		Al = 27.3	Si = 28	P = 31	S = 32	Cl = 35.5
K = 39	Ca = 40	?, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn	? = 68	? = 72	As = 75	Se = 78	Br = 80

There is an unknown element, which turns out to be gallium (Ga), beneath aluminum (Al)…

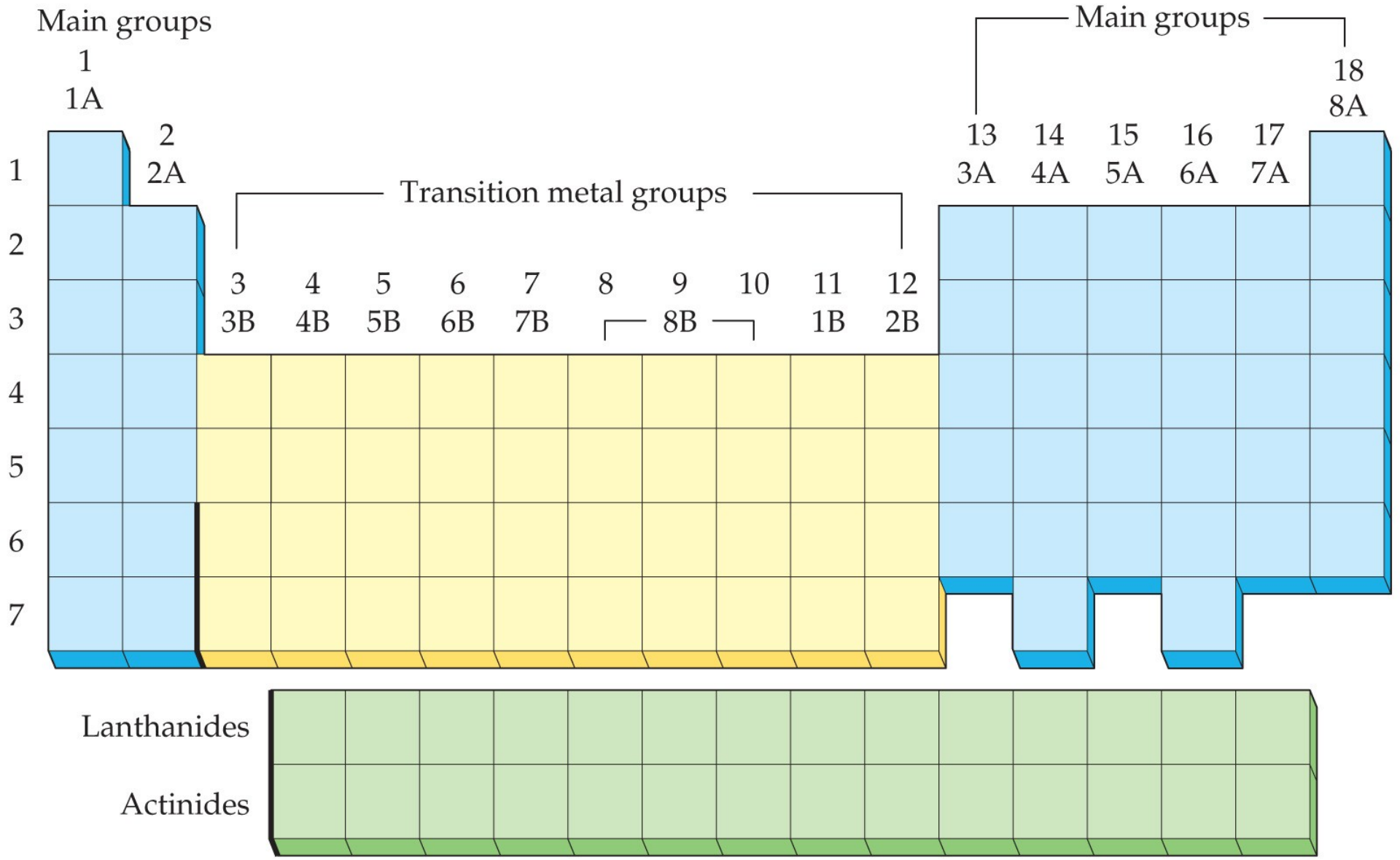
…and another unknown element, which turns out to be germanium (Ge), beneath silicon (Si).

For the unknown elements, Mendeleev used the prefixes eka-, dvi-, and tri-, from the Sanskrit words for one, two, and three, depending upon whether the predicted element was one, two, or three places down from the known element in his table with similar chemical properties.

Elements and the Periodic Table

TABLE 1.2 A Comparison of Predicted and Observed Properties for Gallium (*eka*-Aluminum) and Germanium (*eka*-Silicon)

Element	Property	Mendeleev's Prediction	Observed Property
Gallium	Relative mass	68	69.7
	Density	5.9 g/cm^3	5.91 g/cm^3
	Melting point	Low	29.8 °C
Germanium	Relative mass	72	72.6
	Density	5.5 g/cm^3	5.35 g/cm^3
	Color	Dark gray	Light gray


Main groups
1
1A
2
2A
Transition metal groups
3
3B
4
4B
5
5B
6
6B
7
7B
8
9
8B
10
11
1B
12
2B
Main groups
13
3A
14
4A
15
5A
16
6A
17
7A
18
8A
1
2
3
4
5
6
7
Lanthanides
Actinides

Elements and the Periodic Table

Main Groups

- columns 1A–2A (2 groups)
- columns 3A–8A (6 groups)

Transition Metals: 3B–2B (8 groups, 10 columns)

Inner Transition Metals: 14 groups between 3B and 4B

- lanthanides
- actinides

Some Chemical Properties of the Elements

Property: Any characteristic that can be used to describe or identify matter.

Intensive Properties: *Do not* depend on sample size.

- temperature
- melting point

Extensive Properties: *Do* depend on sample size.

- length
- Volume
- mass

Some Chemical Properties of the Elements

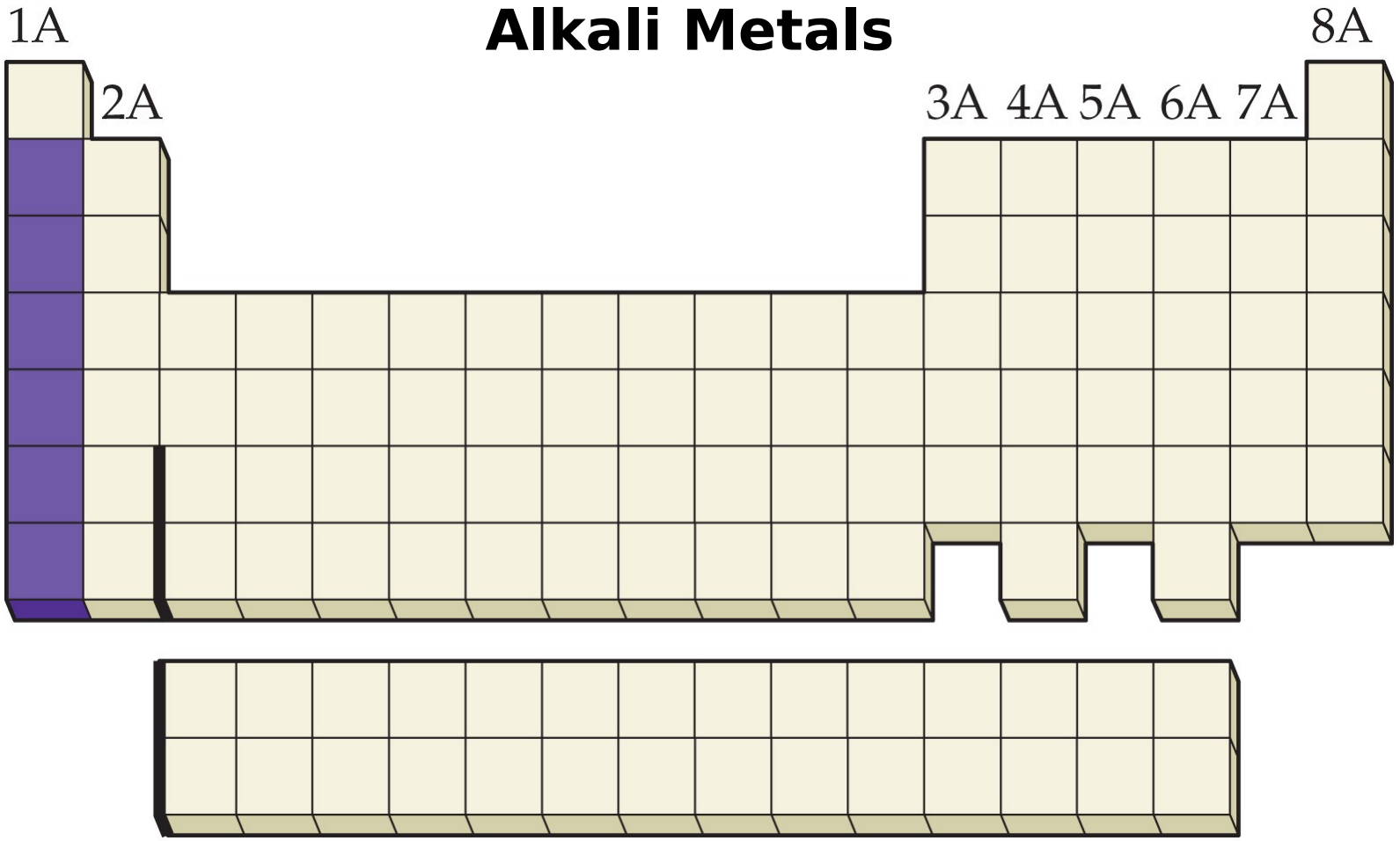
Physical Properties: Characteristics that *do not* involve a change in a sample's chemical makeup.

Chemical Properties: Characteristics that *do* involve a change in a sample's chemical makeup.

TABLE 1.3 Some Examples of Physical and Chemical Properties

Physical Properties		Chemical Properties
Temperature	Amount	Rusting (of iron)
Color	Odor	Combustion (of gasoline)
Melting point	Solubility	Tarnishing (of silver)
Electrical conductivity	Hardness	Hardening (of cement)

Some Chemical Properties of the Elements



Some Chemical Properties of the Elements

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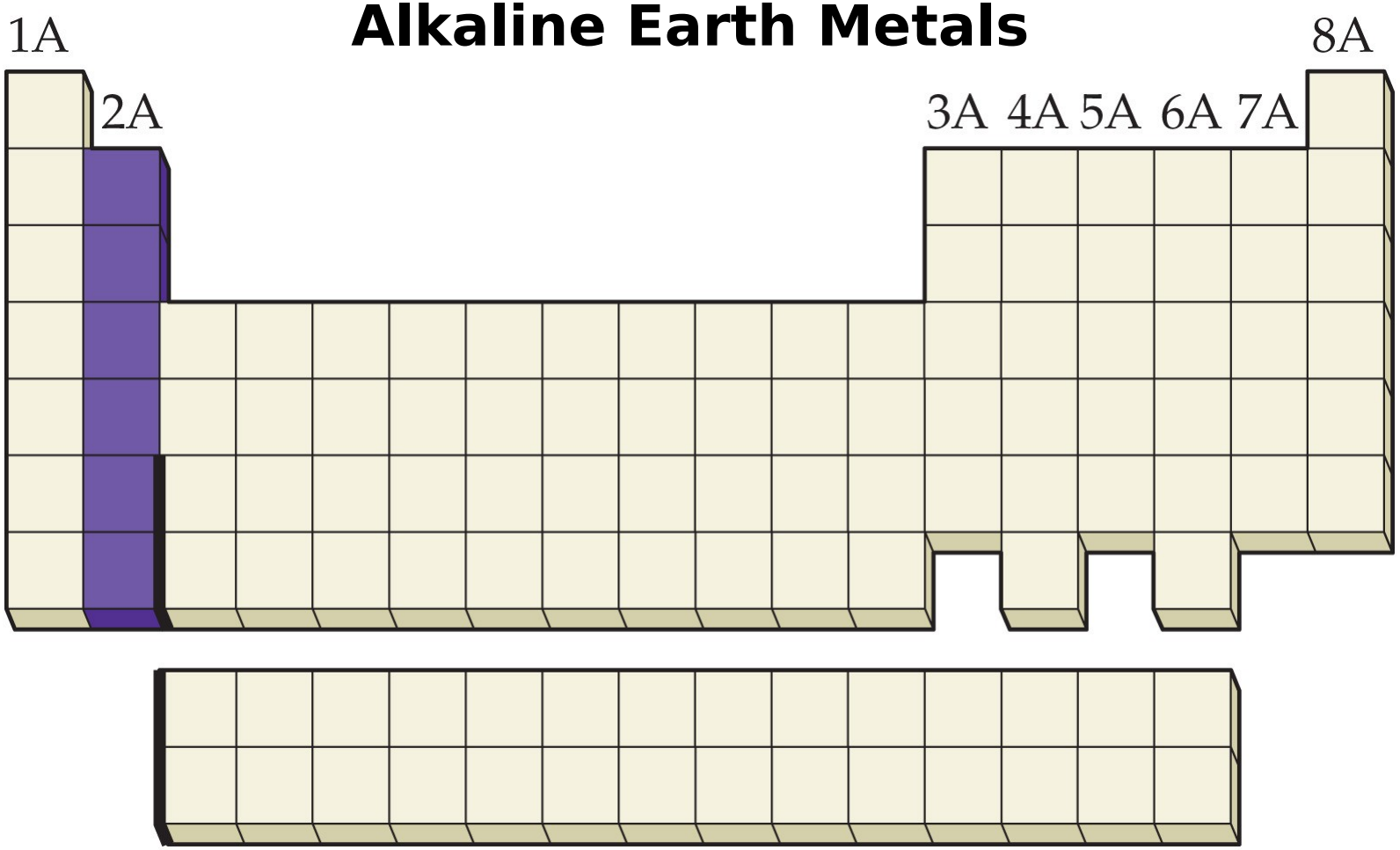
Alkali Metals

- lithium (**Li**), sodium (**Na**), potassium (**K**) , rubidium (**Rb**), caesium (**Cs**), and francium (**Fr**).
- The alkali metals provide one of the best examples of group trends in properties in the periodic table, with well characterized homologous behavior down the group.
- Hydrogen, although a member of Group 1, very rarely exhibits alkali metal behavior. Exists as diatomic species.
- all highly reactive and are never found in elemental forms in nature.

Some Chemical Properties of the Elements



Some Chemical Properties of the Elements

Alkaline Earth Metals

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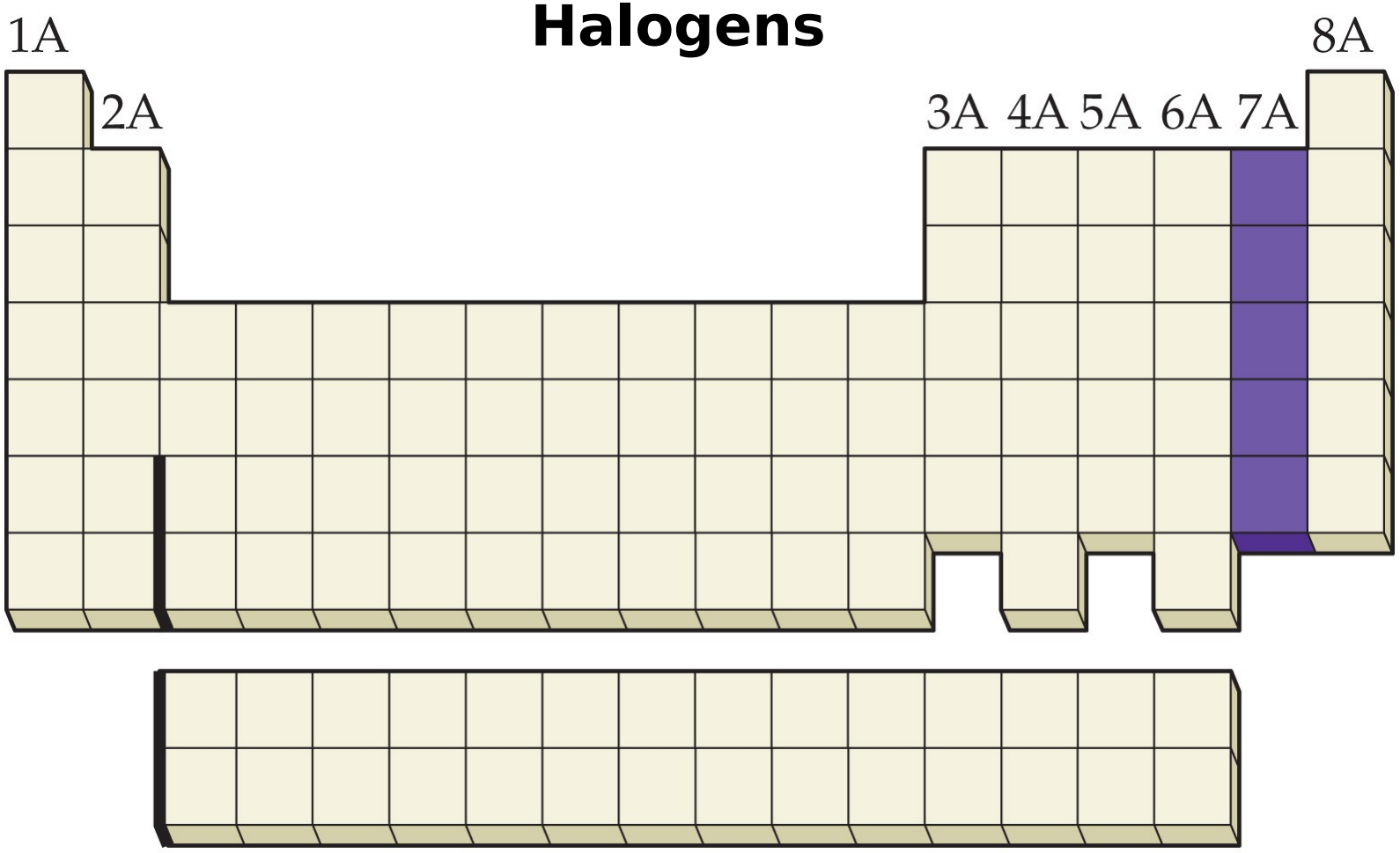
- beryllium (**Be**), magnesium (**Mg**), calcium(**Ca**), strontium (**Sr**), barium (**Ba**) and radium (**Ra**).
- their oxides that give basic alkaline solutions.
- silver colored, soft metals, which react readily with halogens to form ionic salts, and with water, though not as rapidly as the alkali metals, to form strong basic hydroxides.

Some Chemical Properties of the Elements



Some Chemical Properties of the Elements

Halogens

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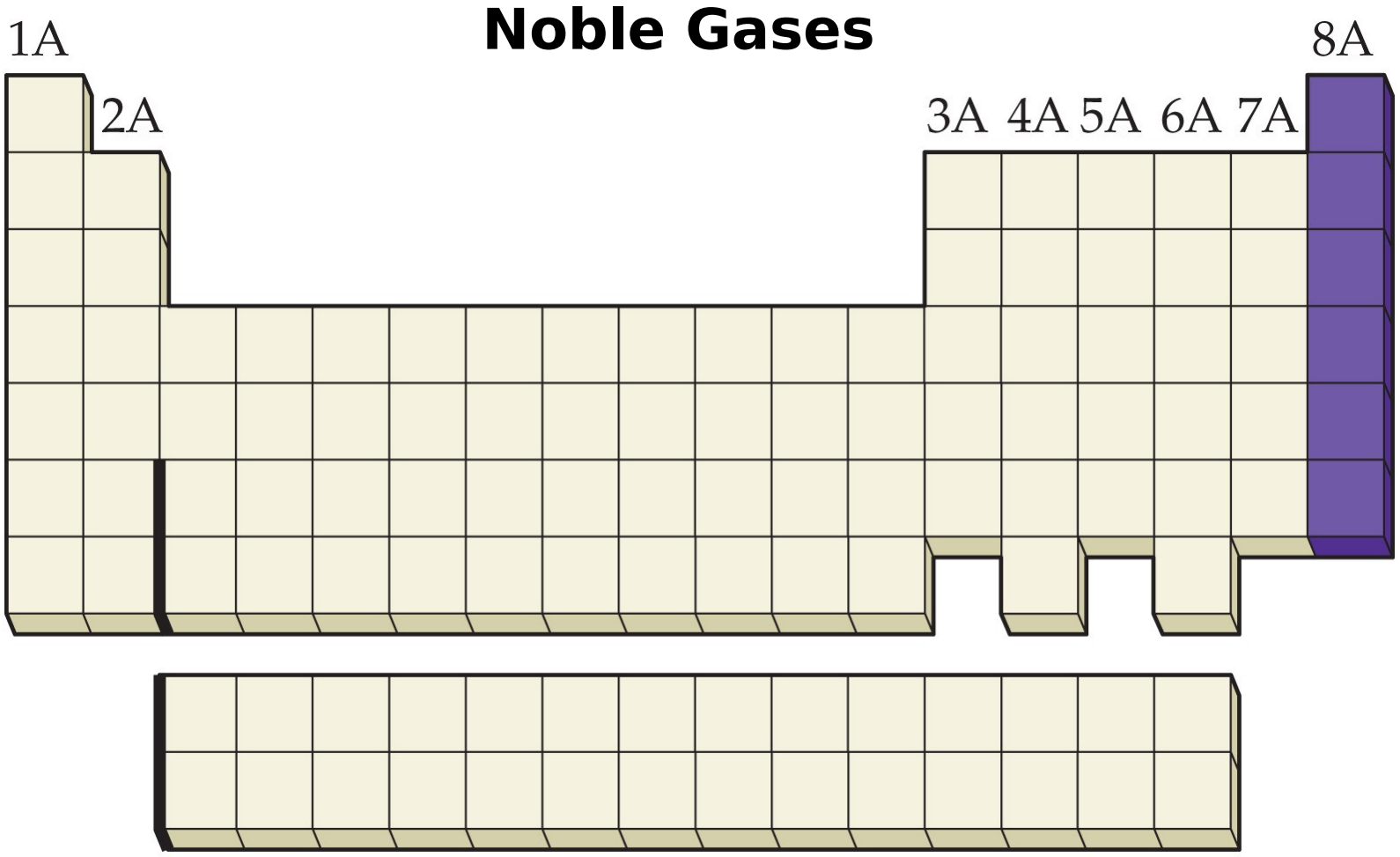
- fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At).
- highly reactive
- found in the environment only in compounds or as ions.
- the halogens exist as diatomic molecules

Some Chemical Properties of the Elements



Some Chemical Properties of the Elements

Noble Gases

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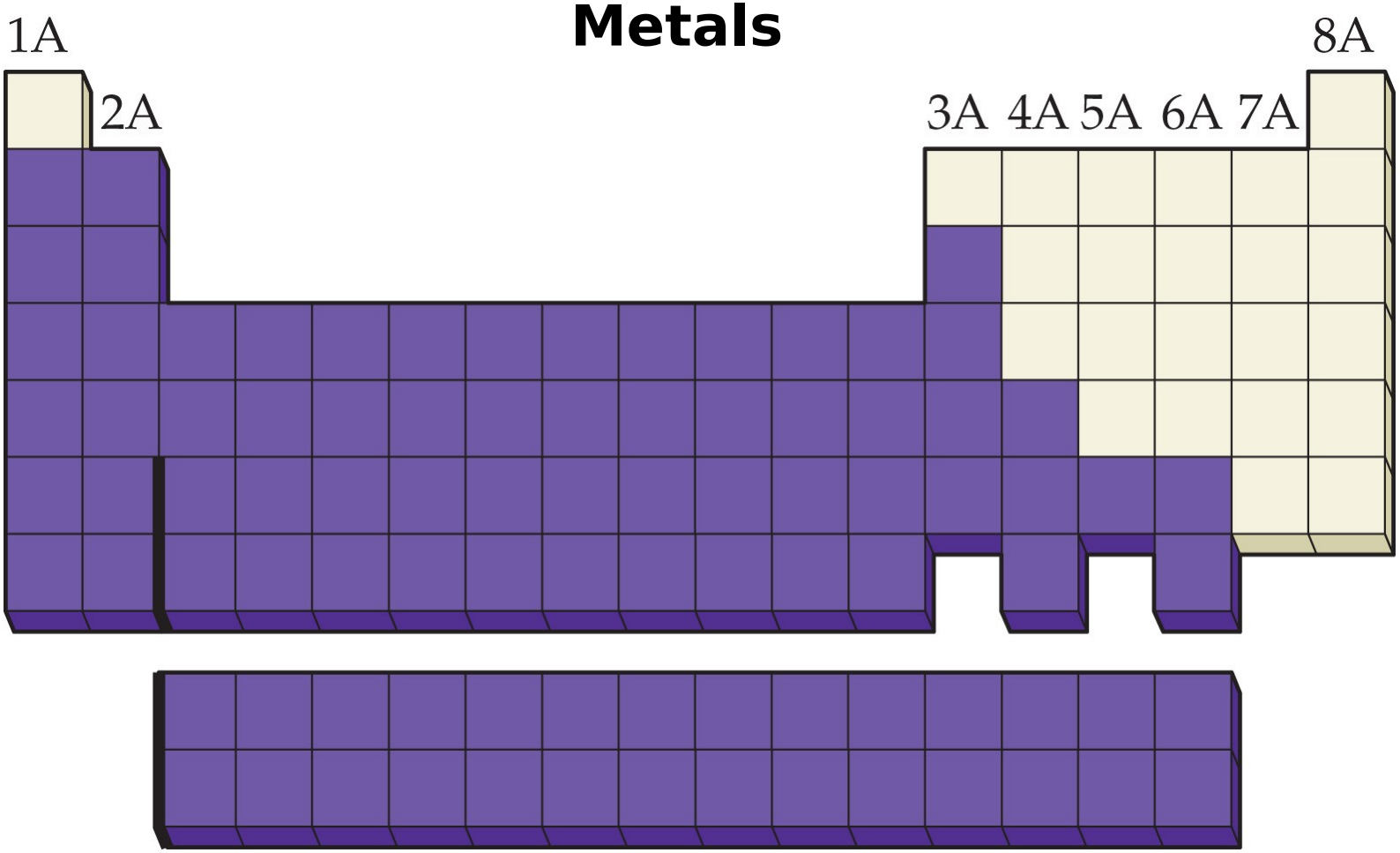
- helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and the radioactive radon (Rn).
- odorless,colorless, monatomic gases, with very low chemical reactivity.

Some Chemical Properties of the Elements



Some Chemical Properties of the Elements

Metals

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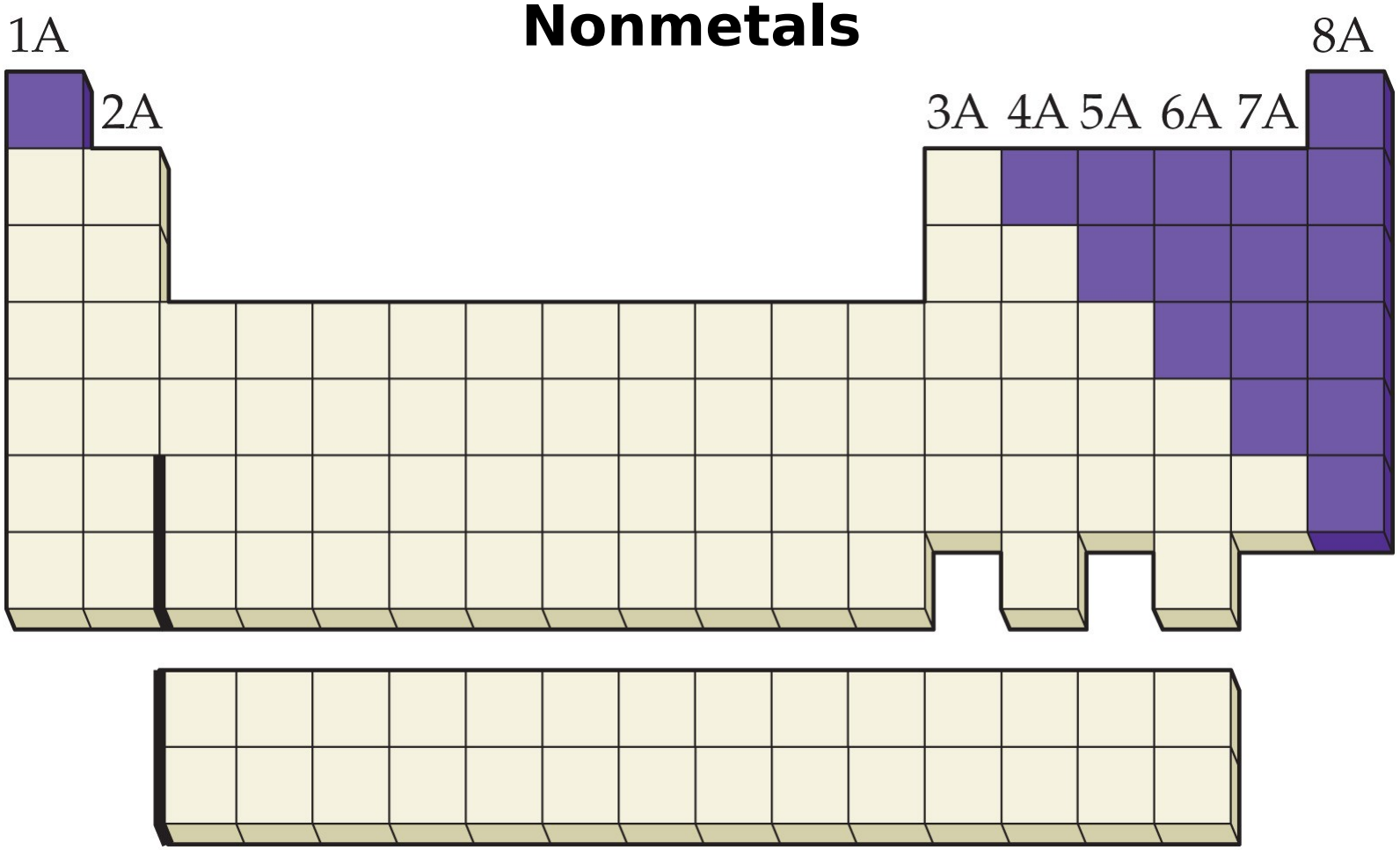
A **metal** is a chemical element that is a good conductor of both electricity and heat and forms cations and ionic bonds with non-metals.

Some Chemical Properties of the Elements



Some Chemical Properties of the Elements

Nonmetals

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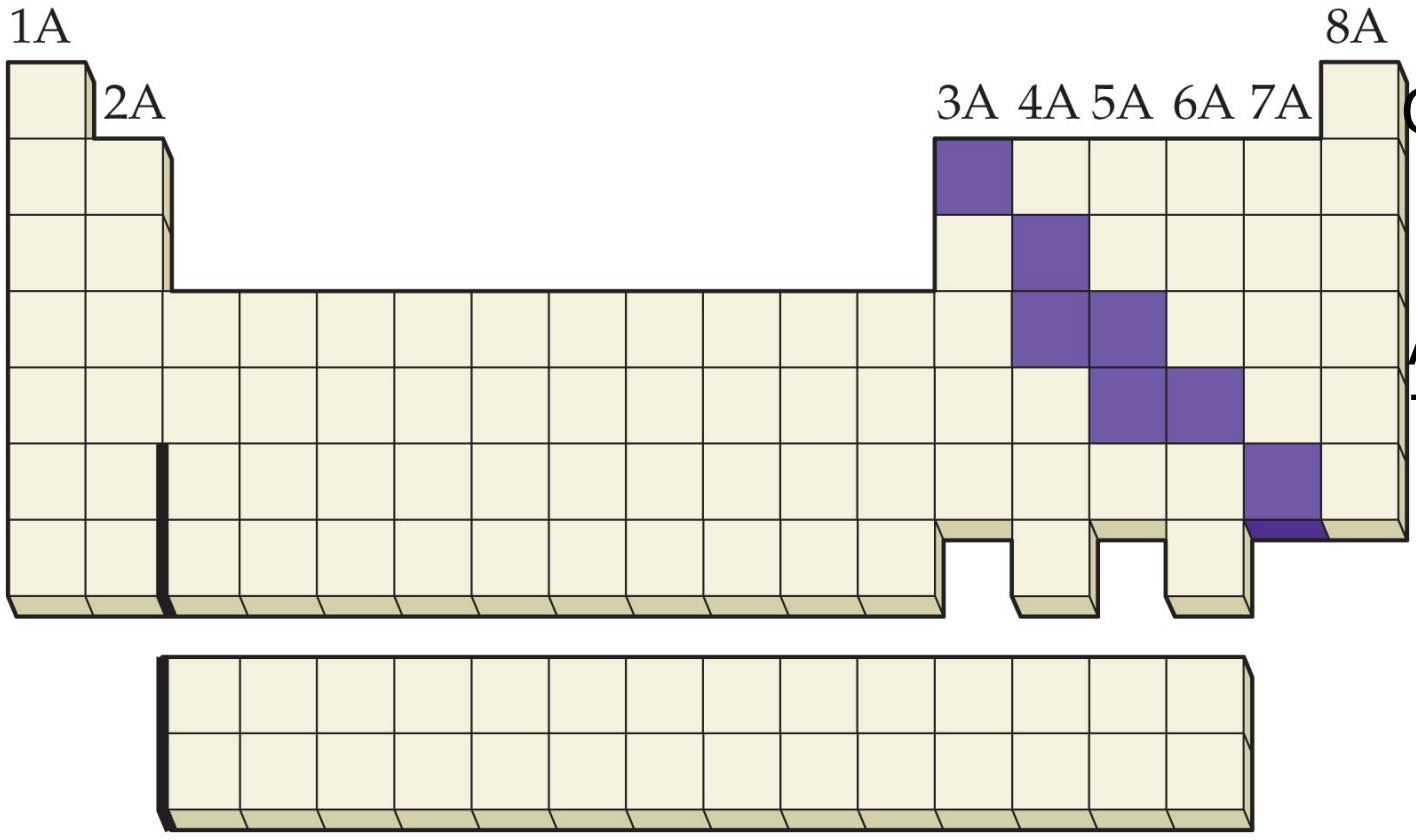
- no rigorous definition for the term "nonmetal“
- poor conductors of heat and electricity
- form acidic oxides vs. metals forming basic oxides.
- dull, brittle solids with low densities.
- high electronegativity

Some Chemical Properties of the Elements

Semimetals – Metalloids



Boron (B)
Silicon (Si)
Germanium (Ge)
Arsenic (As)
Antimony (Sb)
Tellurium (Te)
Polonium (Po)

insulators

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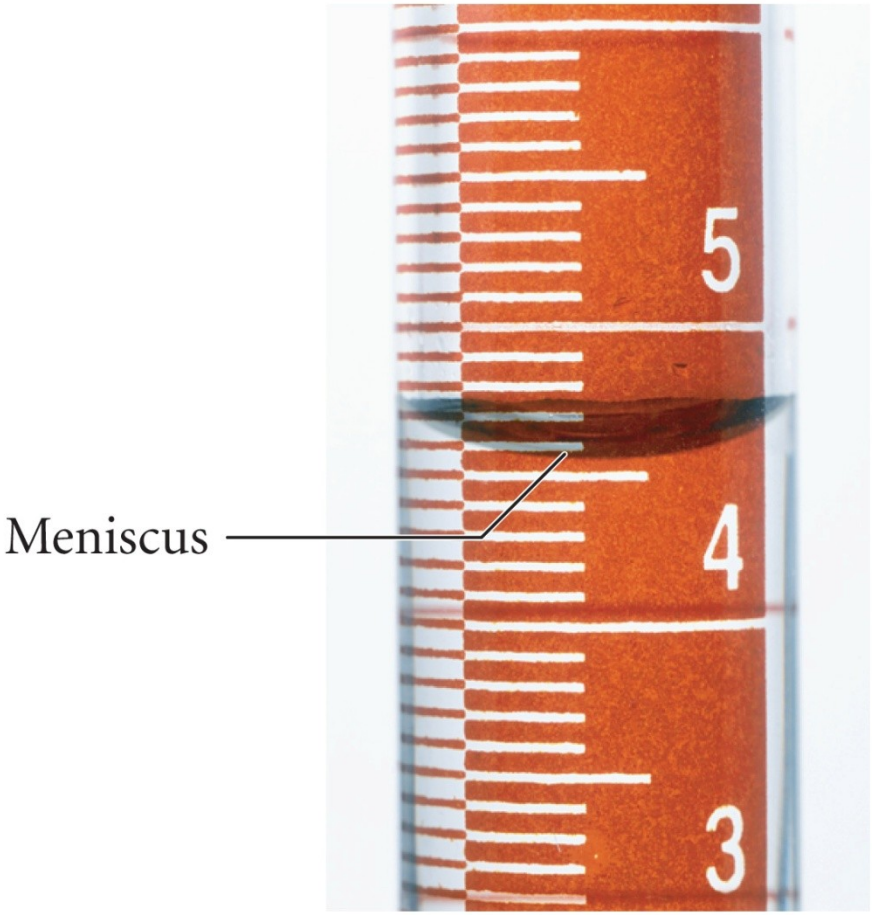
Experimentation & Measurement

The Scientist’s Tools of the Trade

What Is a Measurement?

- a quantitative observation
- Comparison against an agreed-upon standard
- every measurement has a number and a unit



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Experimentation & Measurement: Units

Système International d´Unités

TABLE 1.4 The Seven Fundamental SI Units of Measure

Physical Quantity	Name of Unit	Abbreviation
Mass	kilogram	kg
Length	meter	m
Temperature	kelvin	K
Amount of substance	mole	mol
Time	second	s
Electric current	ampere	A
Luminous intensity	candela	cd

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All other units are derived from these fundamental units.

Units

This point is critical!

- Always write every number with its associated unit
  - Always include units in your calculations
  - **By not following this simple rule, you will get a wrong answer more often than the correct one.**
    - **Smart people go from the A-list to the D-list by ignoring units!!!!!!!!!**
  - using units as a guide to problem solving is called ***dimensional analysis***

TABLE 1.5 Some Prefixes for Multiples of SI Units

Factor	Prefix	Symbol	Example
$1{,}000{,}000{,}000{,}000 = 10^{12}$	tera	T	1 teragram (Tg) $= 10^{12}$ g
$1{,}000{,}000{,}000 = 10^{9}$	giga	G	1 gigameter (Gm) $= 10^{9}$ m
$1{,}000{,}000 = 10^{6}$	mega	M	1 megameter (Mm) $= 10^{6}$ m
$1{,}000 = 10^{3}$	kilo	k	1 kilogram (kg) $= 10^{3}$ g
$100 = 10^{2}$	hecto	h	1 hectogram (hg) $= 100$ g
$10 = 10^{1}$	deka	da	1 dekagram (dag) $= 10$ g
$0.1 = 10^{-1}$	deci	d	1 decimeter (dm) $= 0.1$ m
$0.01 = 10^{-2}$	centi	c	1 centimeter (cm) $= 0.01$ m
$0.001 = 10^{-3}$	milli	m	1 milligram (mg) $= 0.001$ g
$*0.000\ 001 = 10^{-6}$	micro	μ	1 micrometer (μm) $= 10^{-6}$ m
$*0.000\ 000\ 001 = 10^{-9}$	nano	n	1 nanosecond (ns) $= 10^{-9}$ s
$*0.000\ 000\ 000\ 001 = 10^{-12}$	pico	p	1 picosecond (ps) $= 10^{-12}$ s
$*0.000\ 000\ 000\ 000\ 001 = 10^{-15}$	femto	f	1 femtomole (fmol) $= 10^{-15}$ mol

*For very small numbers, it is becoming common in scientific work to leave a thin space every three digits to the right of the decimal point, analogous to the comma placed every three digits to the left of the decimal point in large numbers.

Mass and Its Measurement

Matter: Describes anything with a physical presence—anything you can touch, taste, or smell. Any physical object whether solid, liquid, or gas, that occupies space

Mass: Amount of matter in an object. The quantity of
matter as determined from its weight

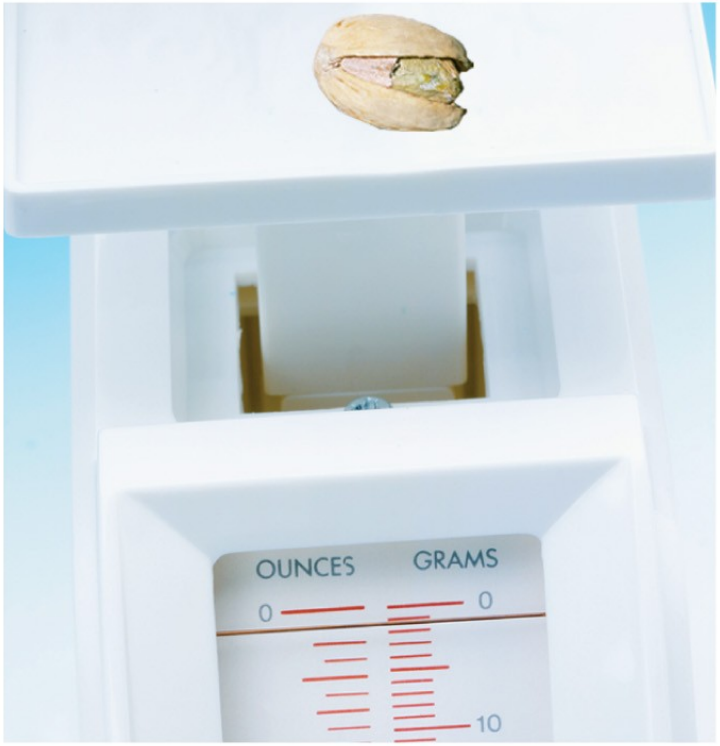
Weight: Measures the force with which gravity pulls on an object (mass).

Mass and Its Measurement

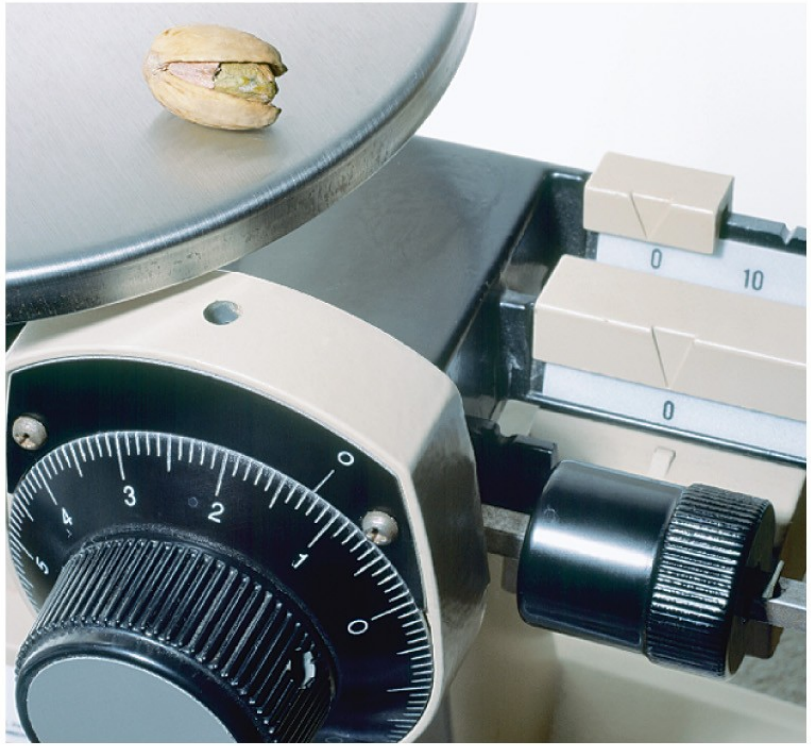
A single-pan balance, which has a sliding counterweight that is adjusted until the weight of the object in the pan is balanced.

Modern electronic balances.

Estimation in Weighing

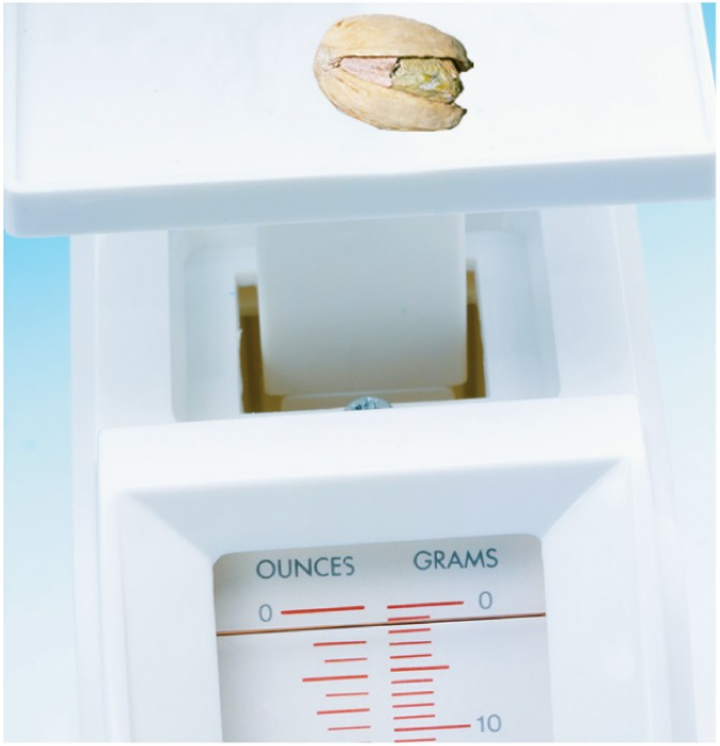


(a)



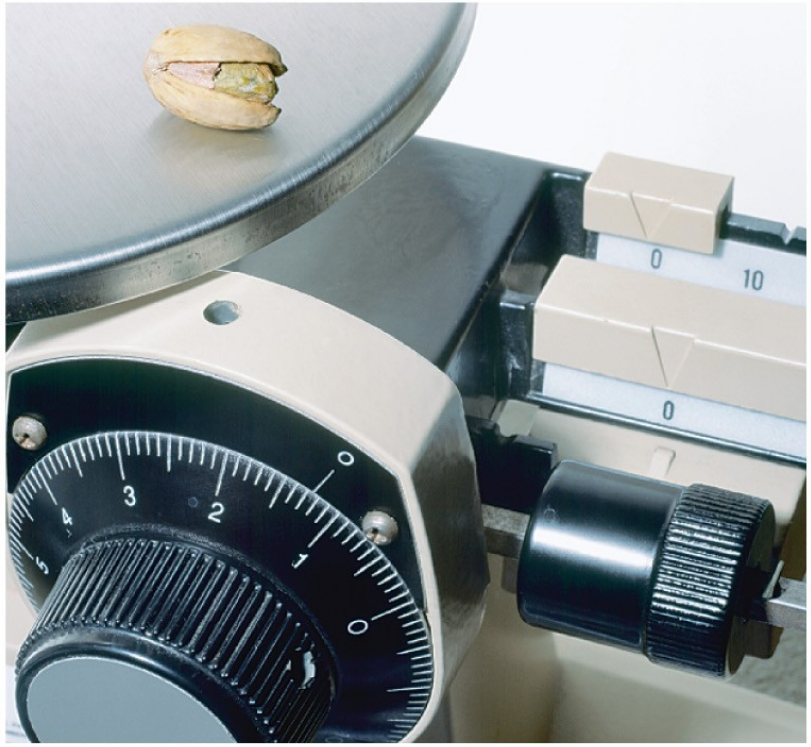
(b)

Estimation in Weighing



(a)

Markings every 1 g
Estimated reading 1.2 g



(b)

Markings every 0.1 g
Estimated reading 1.27 g

Length and Its Measurement

The Meter

- **1790**: One ten-millionth of the distance from the equator to the North pole along a meridian running through Paris, France.

- **1889**: Distance between two thin lines on a bar of platinum-iridium alloy stored near Paris, France.

- **1983**: The distance light travels in 1/299,792,458 of a second.

Temperature

- measure of the average amount of kinetic energy
  - higher temperature = larger average kinetic energy
- heat flows from matter with high thermal energy into matter having low thermal energy
  - until they reach the same temperature
  - heat is exchanged through molecular collisions between the two materials

0 °C – Water freezes

22 °C – Room temperature

40 °C – Summer day in Death Valley

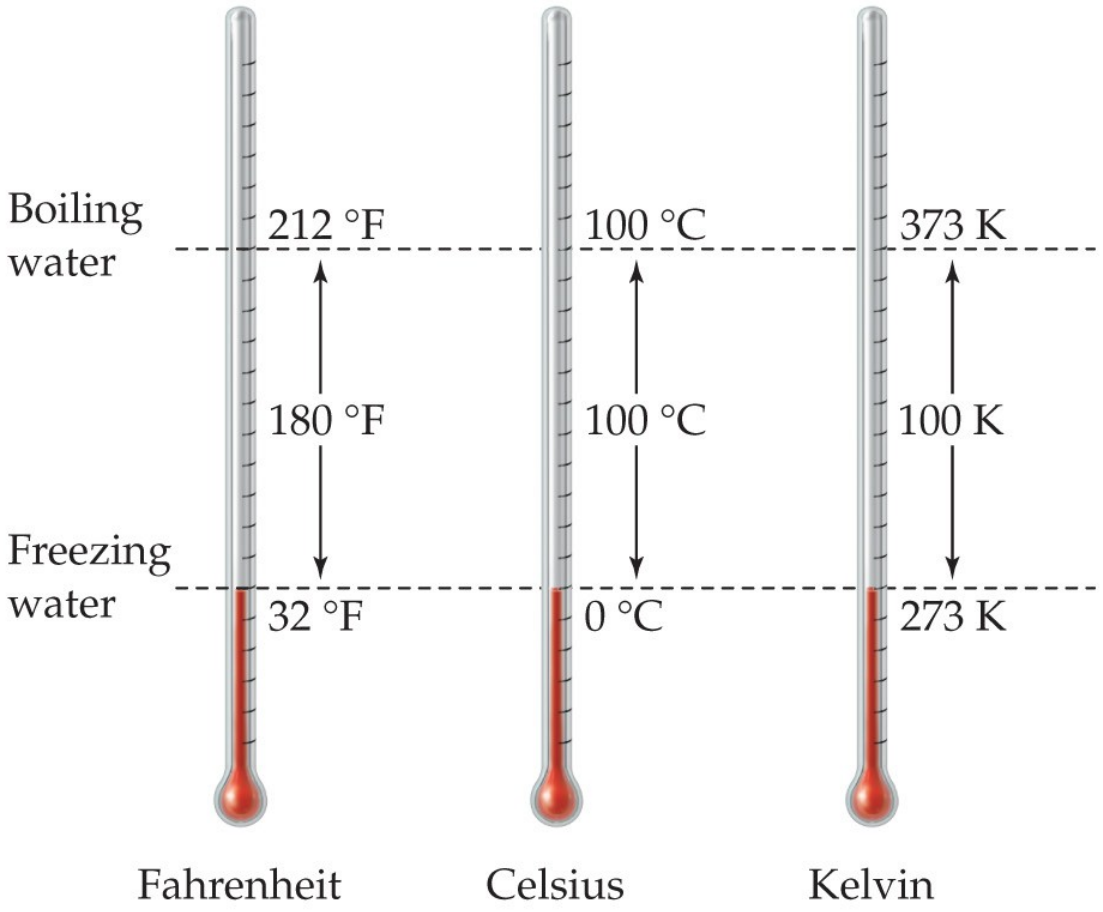
Temperature and Its Measurement

- Fahrenheit Scale, °F
  - used in the U.S.
- Celsius Scale, °C
  - used in all other countries
- Kelvin Scale, K
  - absolute scale
    - no negative numbers
  - directly proportional to average amount of kinetic energy
  - 0 K = absolute zero

$$°F = \left(\frac{9\ °F}{5\ °C}\right)°C + 32\ °F$$

$$°C = \left(\frac{5\ °C}{9\ °F}\right)(°F - 32\ °F)$$

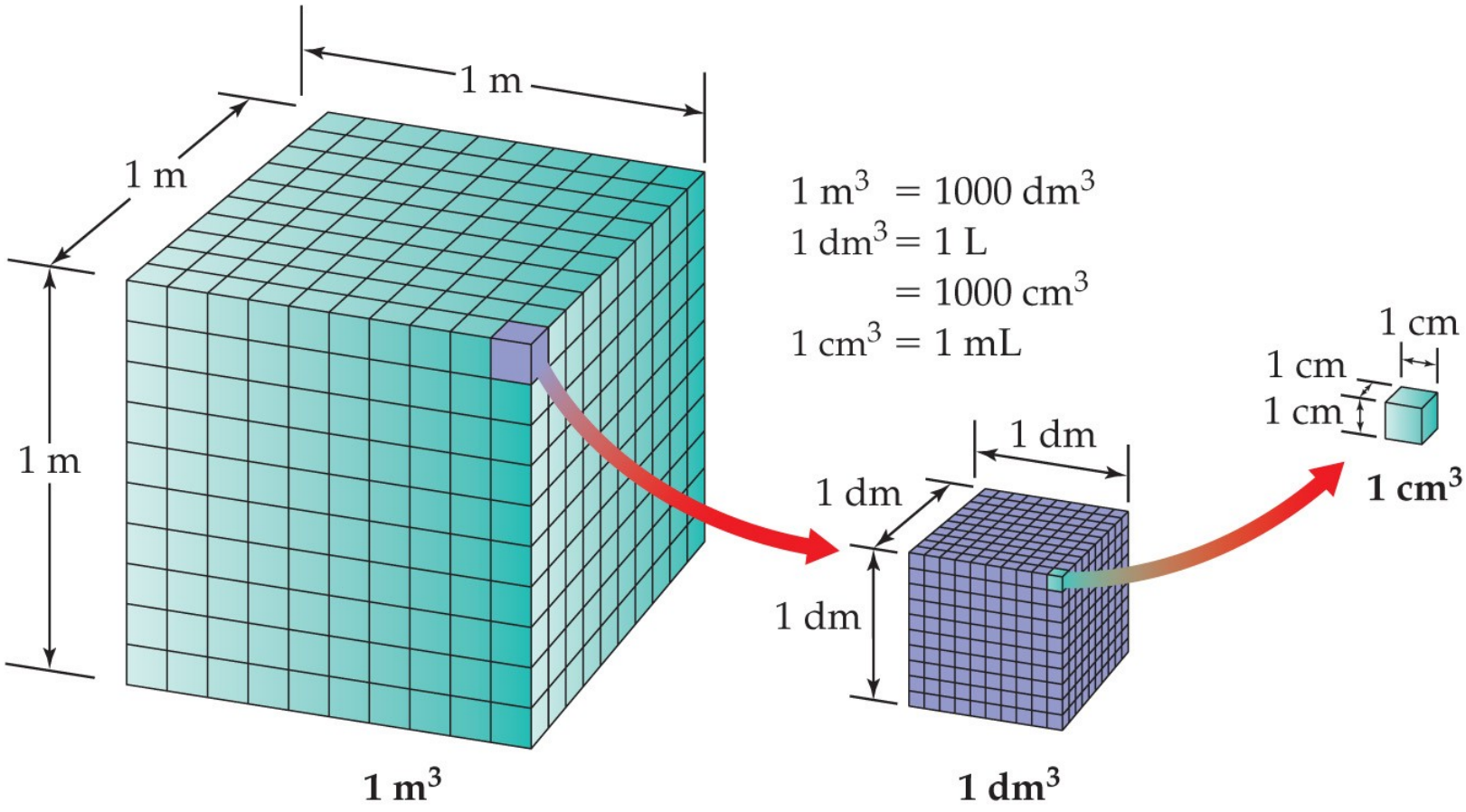
$$K = °C + 273.15$$


Boiling water
212 °F
100 °C
373 K
180 °F
100 °C
100 K
Freezing water
32 °F
0 °C
273 K
Fahrenheit
Celsius
Kelvin

Derived Units: Volume and Its Measurement

TABLE 1.6 Some Derived Quantities

Quantity	Definition	Derived Unit (Name)
Area	Length times length	m^2
Volume	Area times length	m^3
Density	Mass per unit volume	kg/m^3
Speed	Distance per unit time	m/s
Acceleration	Change in speed per unit time	m/s^2
Force	Mass times acceleration	$(kg \cdot m)/s^2$ (newton, N)
Pressure	Force per unit area	$kg/(m \cdot s^2)$ (pascal, Pa)
Energy	Force times distance	$(kg \cdot m^2)/s^2$ (joule, J)



Each cubic meter contains 1000 cubic decimeters (liters).

Each cubic decimeter contains 1000 cubic centimeters (milliliters).

Measuring Liquid Volume

Derived Units: Density and Its Measurement

TABLE 1.7 Densities of Some Common Materials

Substance	Density (g/cm^3)	Substance	Density (g/cm^3)
Ice (0 °C)	0.917	Human fat	0.94
Water (3.98 °C)	1.0000	Human muscle	1.06
Gold	19.31	Cork	0.22–0.26
Helium (25 °C)	0.000 164	Balsa wood	0.12
Air (25 °C)	0.001 185	Earth	5.54

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$$\text{Density} = \frac{\text{Mass (g)}}{\text{Volume (mL or cm}^3\text{)}}$$

Derived Units: Energy and Its Measurement

Energy: Capacity to supply heat or do work.

Kinetic Energy (E_k): The energy or motion.

Potential Energy (E_p): Stored energy.

Units: 1 calorie (cal) = 4.184 J (joule)

1 Cal = 1000 cal = 1 kcal = 4.184 J

Accuracy, Precision, and Significant Figures

Accuracy: How close to the true value a given measurement is.

- Single measurement: percent error
- Series of measurements: average

Precision: How well a number of independent measurements agree with each other. This can be characterized by the standard deviation.

Accuracy, Precision, and Significant Figures

Mass of a Tennis Ball

Measurement #	Bathroom Scale	Lab Balance	Analytical Balance
1	0.0 kg	54.4 g	54.4418 g
2	0.0 kg	54.5 g	54.4417 g
3	0.1 kg	54.3 g	54.4418 g
(average)	(0.03 kg)	(54.4 g)	(54.4418 g)

Accuracy, Precision, and Significant Figures

Mass of a Tennis Ball

Measurement #	Bathroom Scale	Lab Balance	Analytical Balance
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(average)	(0.03 kg)	(54.4 g)	(54.4418 g)

good accuracy
good precision

Accuracy, Precision, and Significant Figures

Mass of a Tennis Ball

Measurement #	Bathroom Scale	Lab Balance	Analytical Balance
1	0.0 kg	54.4 g	54.4418 g
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3	0.1 kg	54.3 g	54.4418 g
(average)	(0.03 kg)	(54.4 g)	(54.4418 g)

good accuracy
poor precision

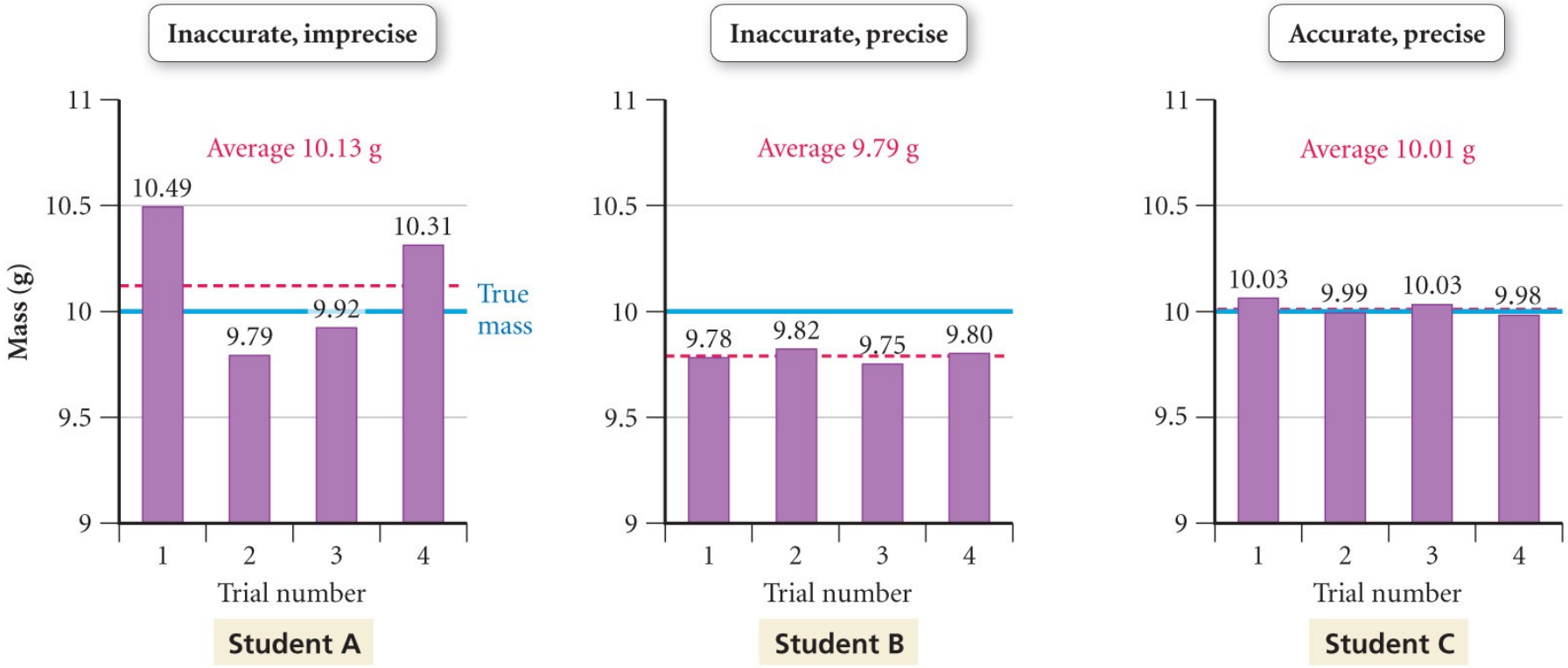
Accuracy, Precision, and Significant Figures

Mass of a Tennis Ball

Measurement #	Bathroom Scale	Lab Balance	Analytical Balance
1	0.0 kg	54.4 g	54.4418 g
2	0.0 kg	54.5 g	54.4417 g
3	0.1 kg	54.3 g	54.4418 g
(average)	(0.03 kg)	(54.4 g)	(54.4418 g)

poor accuracy
poor precision

Accuracy vs. Precision



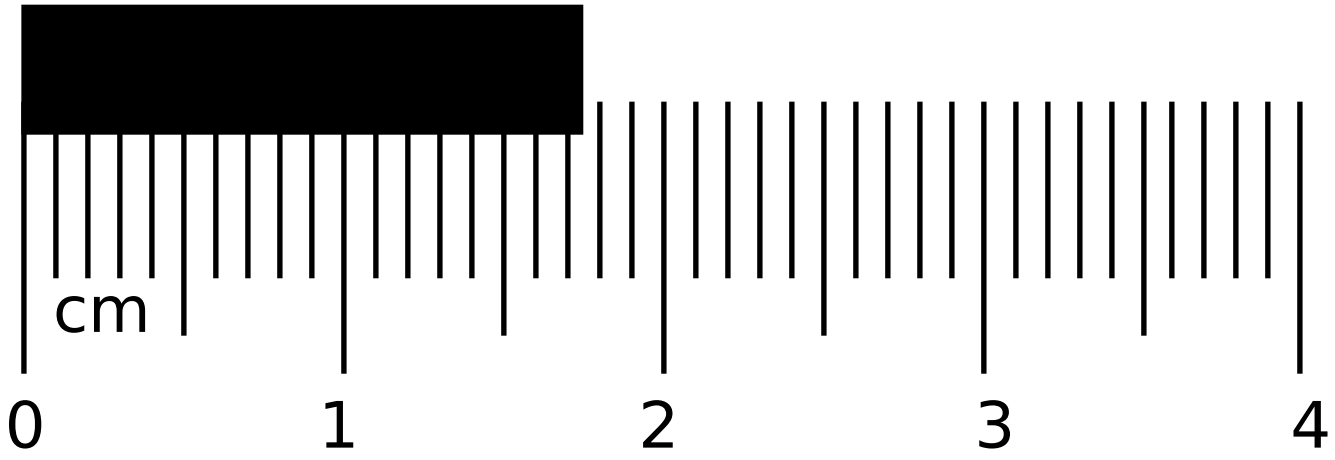
Accuracy, Precision, and Significant Figures

Significant figures: The total number of digits recorded in a measured or calculated quantity. They come from uncertainty in any measurement.

Generally the last digit in a reported measurement is uncertain (estimated).

Exact numbers and relationships (7 days in a week, 30 students in a class, etc.) effectively have an infinite number of significant figures.

Accuracy, Precision, and Significant Figures



1.7 cm < length < 1.8 cm

length = 1.74 cm

Accuracy, Precision, and Significant Figures

Rules for counting significant figures (left-to-right):

1. Zeros in the middle of a number are like any other digit; they are always significant.

   4.803 cm 4 SF

Accuracy, Precision, and Significant Figures

Rules for counting significant figures (left-to-right):

1. Zeros in the middle of a number are like any other digit; they are always significant.

2. Zeros at the beginning of a number are not significant; they act only to locate the decimal point.

0.006 61 g 3 SF (or 6.61×10^{-3} g)

Accuracy, Precision, and Significant Figures

Rules for counting significant figures (left-to-right):

1. Zeros in the middle of a number are like any other digit; they are always significant.

2. Zeros at the beginning of a number are not significant; they act only to locate the decimal point.

3. Zeros at the end of a number and after the decimal point are always significant.
   55.220 K 5 SF

Accuracy, Precision, and Significant Figures

4) Trailing zeros may or may not be significant

- Trailing zeros after a decimal point are significant

  1.050 has 4 sig. figs.

- Zeros at the end of a number without a written decimal point are ambiguous and should be avoided by using scientific notation

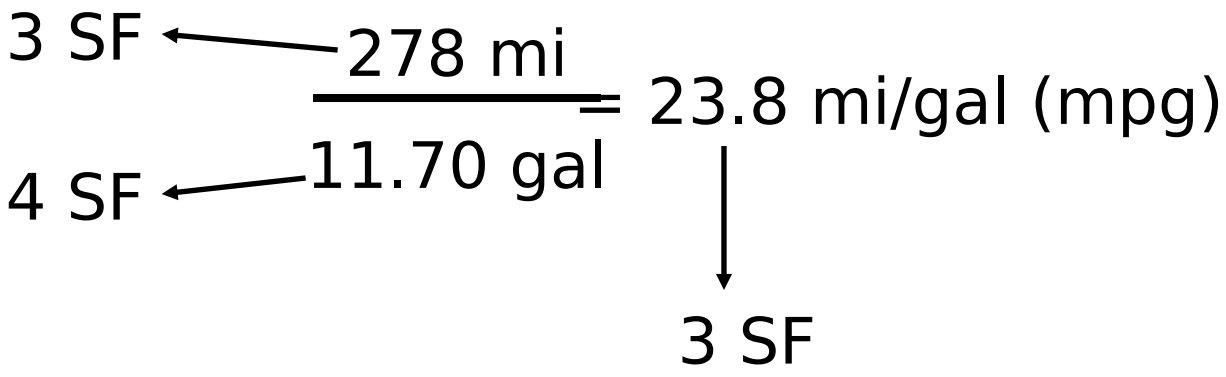
  If 150 has 2 sig. figs. then it is written 1.5×10^2

  If 150 has 3 sig. figs. then it is written

Rounding Numbers

Math rules for keeping track of significant figures:

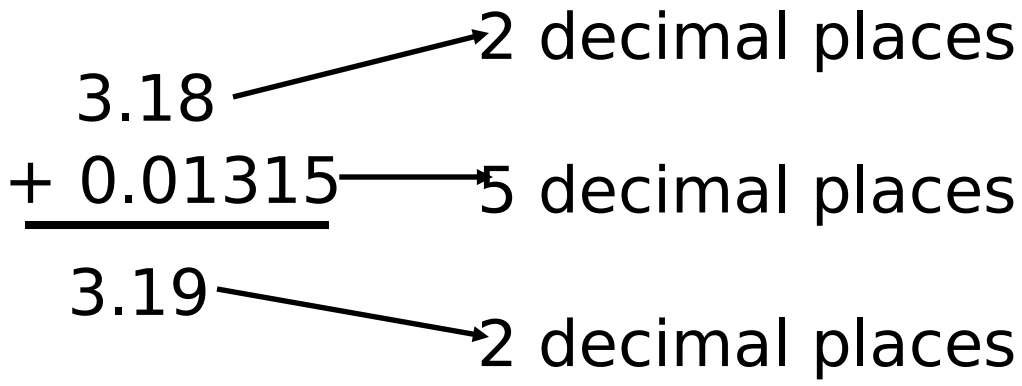
- **Multiplication or division**: The answer can't have more significant figures than any of the original numbers.



Rounding Numbers

Math rules for keeping track of significant figures:

- **Addition or subtraction**: The answer can't have more digits to the right of the decimal point than any of the original numbers.



Rounding Numbers

Rules for rounding off numbers:

1. If the first digit you remove is less than 5, round down by dropping it and all following digits.

   5.66**4525** = 5.66

Rounding Numbers

Rules for rounding off numbers:

1. If the first digit you remove is less than 5, round down by dropping it and all following digits.

2. If the first digit you remove is 6 or greater, round up by adding 1 to the digit on the left.

5.664525 ≈ 5.7

Rounding Numbers

Rules for rounding off numbers:

1. If the first digit you remove is less than 5, round down by dropping it and all following digits.

2. If the first digit you remove is 6 or greater, round up by adding 1 to the digit on the left.

3. If the first digit you remove is 5 and there are more nonzero digits following, round up.

5.664523 = 5.665

Rounding Numbers

Rules for rounding off numbers:

1. If the first digit you remove is less than 5, round down by dropping it and all following digits.

2. If the first digit you remove is 6 or greater, round up by adding 1 to the digit on the left.

3. If the first digit you remove is 5 and there are more nonzero digits following, round up.

4. If the digit you remove is a 5 with nothing following, round down.

5.664525 = 5.66452

Calculations: Converting from One Unit to Another

Dimensional analysis: A method that uses a conversion factor to convert a quantity expressed with one unit to an equivalent quantity with a different unit.

Conversion factor: States the relationship between two different units.
original quantity x **conversion factor** = **equivalent quantity**

Arrange conversion factors so given units cancel

Arrange conversion factor so given unit is on the bottom of the conversion factor

Calculations: Converting from One Unit to Another

Many problems in chemistry involve using relationships to convert one unit of measurement to another

Relationship: 1 m = 39.37 in

Conversion factor: $\frac{1\text{ m}}{39.37\text{ in}}$ Used to convert measurement given in inches to meters

or $\frac{39.37\text{ in}}{1\text{ m}}$ Used to convert measurement given in Meters to inches

Calculations: Converting from One Unit to Another

Incorrect Method

$$69.5\ \text{in} \times \frac{39.37\ \text{in}}{1\ \text{m}} = 2740\ \text{in}^2/\text{m}$$

starting quantity

conversion factor

??

Calculations: Converting from One Unit to Another

Correct Method

$$69.5\ \text{in} \times \frac{1\ \text{m}}{39.37\ \text{in}} = 1.77\ \text{m}$$

starting quantity

conversion factor

equivalent quantity